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Docket No.: ST97001CI2(209-US-CIP2)
09/604,595

REMARKS

STATUS SUMMARY

Claims 1-37 are pending in the present application. Claims 1-36 are rejected under 35 U.S.C. § 112, first paragraph, as failing to comply with the enablement requirement. Claims 11-15 and 29-36 are rejected under 35 U.S.C. § 101 as being directed to non-statutory subject matter. The Examiner has also rejected claims 1 and 6 under 35 U.S.C. § 102(b) as being anticipated by *Lee* (U.S. Pat. No. 5,267,260), and has also rejected claim 6 under 35 U.S.C. § 103(a) as being unpatentable over *Lee et al.* Further, the Examiner has rejected claims 39-42 and 44 under 35 U.S.C. § 103(a) as being unpatentable over *Lee* in view of *Langberg et al.* (U.S. Pat. No. 5,852,630). The Examiner has also objected to the specification because of its lack of page numbers.

These formal matters identified in the Office Action are addressed herein below.

RESPONSE TO OBJECTION TO SPECIFICATION

The Examiner has objected to the specification with the suggestion that its pages be numbered. The specification, consisting of 34 pages, with such numbering and a corrected docket number on each page is appended to this response.

In view of the foregoing, Applicants respectfully submit that the objection to the specification has now been overcome, and therefore request that the Examiner's objection be withdrawn at this time.

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RESPONSE TO CLAIM REJECTIONS UNDER 35 USC § 112

The Examiner has rejected claims 1-36 under 35 U.S.C. § 112, first paragraph, as failing to comply with the enablement requirement. Specifically, claims 1-36 recite the limitation "disspreading a PN code from a spread spectrum signal," when the claim invention is actually "disspreading a spread spectrum signal using a PN code." Accordingly, Applicants have amended claims 1, 6, 16, 21, 25 and 33 to reflect that the claimed invention is in fact disspreading a spread spectrum signal using a PN code. Applicants have also amended a portion of the specification as set forth above to conform to the language of the claims. Applicants believe these amendments add no new matter.

Additionally, the Examiner has rejected claims 23, 24, 27, 38, 31, 32, 35 and 36 under 35 U.S.C. § 112, first paragraph, as failing to comply with the enablement requirement. Specifically, the Examiner states that these claims recite the limitation "a fourth multiplier," "multiplying ... to obtain a fourth product," and "means for multiplying ... to obtain a fourth product" that is not disclosed in the specification. Applicants respectfully traverse these rejections.

In his rejection, the Examiner makes reference to FIG. 9 and page 18, line 11 – page 19, line 9 of the specification. Applicants note that page 18, lines 20-21 of the specification states that "the circuitry 900 of FIG. 9 uses half the number of multipliers as the circuitry 800 of FIG. 8." An examination of FIG. 8 shows four pairs 804, 806, 808, 810 of I and Q latches, corresponding I-Q switches 812 between each of the latches, and four "one bit multipliers 814 for applying the PN chips." FIG. 8, page 18, lines 2-7.

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Based on the foregoing and the amendment of claims 1, 6, 16, 21 25 and 33, Applicants believe that claims 1-36 are now in a condition for allowance and respectfully request that the Examiner withdraw his rejections of claims 1-36 under 35 U.S.C. § 112, first paragraph.

RESPONSE TO CLAIM REJECTIONS UNDER 35 USC § 101

The Examiner has rejected claims 11-15 and 29-36 under 35 U.S.C. § 101 because the claimed invention is directed to non-statutory subject matter, specifically, a "computer data signal embodied in a carrier wave." The Examiner states that these claims are directed towards a computer data signal that merely consists of "1" and "0" to represent the coded signal.

Applicants respectfully traverse this rejection. Reviewed as a whole, and given its broadest reasonable interpretation, claims 11-15 and 29-36 are statutory article of manufacture claims. For example, claim 11 recites a computer program embodied in a computer-readable medium — the carrier wave -- with two claim limitations: "(a) a receiving source code segment comprising means for receiving a spread spectrum signal, ... ; and (b) a processing source code segment comprising: (i) means for selecting one of the in-phase portion and the quadrature-phase portion; and (ii) means for multiplying the selected portion of one of the plurality of signal samples with one of a plurality of PN code chips to obtain a first product."

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To summarize what is set forth in the Manual of Patent Examining Procedure ("MPEP") § 2106 and the Appendix to Examination Guidelines for Computer-Related Inventions (page 2100-23), the claimed invention in claim 11:

- (a) has a practical application -- the claimed invention processes a spread spectrum signal by despreading the spread spectrum signal using a PN code with an optimal number of multipliers and adders;
- (b) is in the technological arts, i.e., the disclosed invention uses a general purpose computer system for processing communication data;
- (c) is not a computer program *per se* because it is not a mere program listing; the claims define a functional relationship between the computer program and other elements that permits the computer program's functionality to be realized;
- (d) is not a data structure *per se* because the claimed invention clearly does not define a data structure;
- (e) is not merely non-functional descriptive material because, as noted in subparagraph (c) above, the disclosed invention defines a functional relationship between the computer program and other elements that permits the computer program's functionality to be realized;
- (f) is not a natural phenomenon; most likely, a "computer data signal" would not occur as a natural phenomenon and absent evidence to support it, such a position is untenable;
- (g) is not a series of steps to be performed on a computer because it does not describe a method of processing communication data; and
- (h) is a specific machine or manufacture because it describes a specific article of manufacture, i.e., a computer program with two claim limitations embodied in a computer-readable medium, the carrier wave.

Moreover, independent claims 11 and 29 are similar to claim 13 in the
Examination Guidelines for Computer-Related Inventions, Example: Automated

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Manufacturing Plant (hereinafter referred to as the "Automated Manufacturing Plant Example"), that characterizes such a claim as a statutory article of manufacture claim. Claim 13 of the Automated Manufacturing Plant Example is "[a] computer data signal embodied in a carrier wave comprising: a. a compression source code segment comprising ... [recites self-documenting source code]; and b. an encryption source code segment comprising: ... [recites self-documenting source code]." This claim is characterized as a statutory article of manufacture claim in the Automated Manufacturing Plant Example. Claim 29 is similar to claim 11 in that both are "computer data signals," with claims 12-15 and 30-36, respectively, being dependent claims thereon.

Therefore, based on MPEP § 2106, the Appendix to Examination Guidelines for Computer-Related Inventions (page 2100-23), and the Automated Manufacturing Plant Example, Applicants believes that claims 11-15 and 29-36 are clearly directed to statutory subject matter and thus respectfully request that the rejection of claims 11-15 and 29-36 under 35 U.S.C. § 101 be withdrawn.

RESPONSE TO CLAIM REJECTIONS UNDER 35 USC § 102(b)

The Examiner has rejected claims 1 and 6 under 35 U.S.C. §102(b) as being anticipated by the *Lee* patent (U.S. Pat. No. 5,267,260). MPEP § 2131 provides:

"A claim is anticipated only if each and every element as set forth in the claim is found, either expressly or inherently described, in a single prior art reference." *Verdegaal Bros. v. Union Oil Co. of California*, 814 F.2d 628, 631, 2 USPQ2d 1051, 1053 (Fed. Cir. 1987). ... "The identical invention must be shown in as complete detail as is contained in the ... claim." *Richardson v. Suzuki Motor Co.*, 868 F.2d 1226, 1236, 9 USPQ2d

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1913, 1920 (Fed. Cir. 1989). The elements must be arranged as required by the claim,

The *Lee* patent does not teach each and every claimed element of claims 1 and 6. Therefore, Applicants respectfully traverse these rejections.

CLAIM 1

The Examiner states: “[r]egarding claim 1, *Lee* discloses a system for despreading (column 4, lines 26-37) a spread spectrum signal using a PN code, wherein the spread spectrum signal comprises a plurality of signal samples (FIG. 2, blocks 33 and 34, column 3, lines 19-43, wherein it is well known that an A/D converter creates signal samples from a received signal), each signal sample having an in-phase portion and a quadrature-phase portion, and wherein the PN code comprises a plurality of chips, the system comprising:

a switch (FIG. 2, block 3, column 4, lines 26-37) for selecting one of the in-phase portion and the quadrature-phase portion; and

a first multiplier (FIG. 2, block 39, column 4, lines 26-37) coupled to the switch for multiplying the selected portion of one of the plurality of signal samples with one of the plurality of PN code chips to obtain a first product.”

In response, Applicants respectfully disagree that the *Lee* patent teaches each and every aspect of the claimed invention in claim 1 either explicitly or impliedly as required under 35 U.S.C. § 102(e) and MPEP §§ 706 and 2131. What the *Lee* patent teaches is the following: the signal values of the I and Q channels are integrated in first integrator 35 and second integrator 36, respectively, by N times (where N is an integer) of one PN period; the results of the two integrated signals are compared in comparator 37, and the

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signal having the larger magnitude is output in the multiplexer 38 to the despreading demodulator 39 (FIG. 2, blocks 35, 36, 37 and 39, column 4, lines 26-37).

In contrast, the first limitation of claim 1 refers to a switch selecting "one of the in-phase portion and the quadrature-phase portion." This is done prior to the multiplication operation and is not taught by *Lee*; there, the comparator 37 selects the signal of higher magnitude after integration. Moreover, the second limitation of claim 1 refers to a first multiplier coupled to the switch of the first limitation for *multiplying the selected portion of one of the plurality of signals with one of the plurality of PN code chips to obtain a first product.* *Lee* does not teach multiplying only the selected portion of a spread spectrum signal, nor does it teach obtaining a first product, it merely does a comparison in a comparator.

Therefore, the *Lee* patent fails to teach or describe all of Applicants' claim limitations in independent claim 1. Thus independent claim 1 is in condition for allowance and Applicants respectfully request that the rejection of claim 1 under 35 U.S.C. § 102(b) be withdrawn.

CLAIM 6

Claim 6 is a method claim with similar features to that of claim 1 and the foregoing also applies to claim 6. Therefore, Applicants believe that claim 6 is also in a condition for allowance and respectfully request that the Examiner withdraw the rejection of this claim under 35 U.S.C. § 102(b).

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RESPONSE TO CLAIM REJECTIONS UNDER 35 USC § 103(a)

The Examiner has also rejected claim 6 under 35 U.S.C. §103(a) as being unpatentable over *Lee* (U.S. Pat. No. 5,267,260) in view of *Langberg et al.* (U.S. Pat. No. 5,852,630). The Examiner states that *Langberg et al.* teaches that the method and apparatus for a transceiver warm start activation procedure with precoding can be implemented in software stored in a computer-readable medium and that “one skilled in the art at the time the invention was made would have clearly recognized that the method of *Lee* would have been implemented into software. ... Therefore, it would have been obvious to have used the software in *Lee* as taught by *Langberg et al.* in order to reduce cost and improve the adaptability and flexibility of the communication system.” Applicants respectfully traverse this rejection.

The Examiner has failed to establish a *prima facie* case of obviousness as required by 35 U.S.C. §103(a), the applicable case law and MPEP §2142 because the Examiner has failed to show all of the following: 1) a motivation or suggestion to combine *Lee* and the additional elements, either in the references themselves or in the knowledge generally available to one of ordinary skill in the art, to modify the reference (i.e., *Lee*) or to combine reference teachings; 2) a reasonable expectation of success; and 3) that *Lee* and the additional elements when combined teach or suggest all the claim limitations.

The MPEP § 2142 specifically states that the “examiner bears the initial burden of factually supporting any *prima facie* conclusion of obviousness. If the examiner does not produce a *prima facie* case, the applicant is under no obligation to submit evidence of

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nonobviousness.” Additionally, MPEP § 2142 also states that the “initial burden is on the examiner to provide some suggestion of desirability of doing what the inventor has done. ‘To support the conclusion that the claimed invention is directed to obvious subject matter, either the references must expressly or impliedly suggest the claimed invention or the examiner must present a convincing line of reasoning as to why the artisan would have found the claimed invention to have been obvious in light of the teachings of the references.’” Official notice unsupported by documentary evidence should only be taken by the examiner when the facts asserted to be well-known, or to be common knowledge in the art are capable of instant and unquestionable demonstration as being well-known.

MPEP § 2144.03 A.

First, all claim limitations are not taught by a combination of the references for the reasons stated in Applicants’ traversal of the rejection of claims 1 and 6; that is, *Lee* and *Langberg et al.* do not teach all of the claim limitation of claim 6, specifically, they do not teach obtaining a first product. Second, the Examiner has failed to show that there is a suggestion or motivation to combine *Lee* and *Langberg et al.*

Langberg et al. cannot be combined *Lee* for the purpose of incorporating an element related to software stored in a computer-readable medium without meeting the requirements set forth above. It is well known that “any software process can be transformed into an equivalent hardware process, and any hardware process can be transformed into an equivalent software process.” *Overhead Door Corp. v. Chamberlain Group, Inc.*, 194 F.3d 1261, 52 USPQ2d 1321, 1326 (Fed. Cir. 1999). Therefore it is a

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truism that one skilled in the art can implement any element of his invention in either software or hardware, at his own choosing.

For example, in *Overhead Door Corp.*, the court found that in a means-plus-function element, a "switch means," also covered a software-based embodiment described in a drawing. *Id.* at 1273. However, when looking at a software-based embodiment in the accused product, the court in *Overhead Door Corp.* stated that although the software-based embodiment performed the same function as the corresponding element in the patented product, the software-based embodiment constituted a different "structure" than the software disclosed in the patent because it used a different algorithm to perform the same function. *Id.* at 1273. Thus, in addition to the traditional requirements for modifying or combining the cited references as proposed by the Examiner, there is the additional requirement when determining whether the combined references teach or suggest all the claim limitations that any software-based embodiments have the same structure, i.e., the algorithms used to perform the function in question must be the same.

This additional requirement has not been met and therefore Applicants respectfully submit that the Examiner has failed to show a motivation or suggestion to combine *Lee* and *Langberg et al.* and a reasonable expectation of success; and also that *Lee* and *Langberg et al.* when combined teach or suggest all the claim limitations, that is, *Langberg et al.* does not supply the missing elements of *Lee*.

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Therefore independent claim 6 is in condition for allowance and Applicants respectfully request that the rejection of claim 6 under 35 U.S.C. § 103(a) be withdrawn.

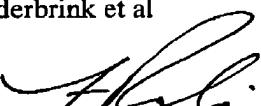
CONCLUSION

In light of the above amendments and remarks, it is respectfully submitted that the present application is now in proper condition for allowance, and an early notice to such effect is earnestly solicited.

If any small matter should remain outstanding after the Patent Examiner has had an opportunity to review the above Remarks, the Patent Examiner is respectfully requested to telephone the undersigned patent attorney in order to resolve these matters and avoid the issuance of another Official Action.

Respectfully submitted,
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A SPREAD SPECTRUM MATCHED FILTER****1. Cross-Reference To Related Applications**

This application is a continuation in part of Non-Provisional Patent Application Serial No. 09/498,893, filed on February 7, 2000, and entitled IMPROVED DOPPLER CORRECTED SPREAD SPECTRUM MATCHED FILTER, which is a continuation in part of Non-Provisional Patent Application Serial No. 09/145,055, filed on September 1, 1998, and entitled DOPPLER CORRECTED SPREAD SPECTRUM MATCHED FILTER, now U.S. Patent No. 6,044,105, both of which are incorporated by reference.

10 2. Technical Field

This invention relates to electronic communication systems. In particular, the invention relates to an improved system and method for despreading a PN code from a spread spectrum signal in a matched filter.

3. Background Of The Invention

15 Conventionally, data communication systems use narrow band modulation techniques, such as amplitude modulation "AM," frequency modulation "FM," frequency shift keying "FSK," binary phase shift keying "BPSK," quadrature phase shift keying "QPSK," and quadrature amplitude modulation "QAM." With such systems, demodulation at the receiver may be achieved with a relatively small amount of circuitry. However, these 20 types of systems suffer from several problems including multipath fading and narrow band noise.

In contrast, in spread spectrum communication systems, a data spectrum is spread by a pseudo-noise "PN" code at a transmitter while the PN code and the data are synchronized at a receiver. The PN code is composed of a binary sequence that is often referred to as the 25 "chip sequence." The binary symbols in the chip sequence are referred to as "chips" and it is appreciated by those skilled in the art that the transmitter and intended receiver both have

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available the same chip sequence. This technique reduces the adverse effects of multipath fading and narrow band noise. The military has employed spread spectrum communication systems to combat the intentional jamming and detection of radio and satellite communication links. Accordingly, spread spectrum communication systems have attracted 5 increased attention as a promising technique for radio frequency transmission of binary data in the non-military sector.

One of the two most common spread spectrum techniques, referred to as frequency hopping spread spectrum "FH-DSS," employs the chip sequence to shift, over a wide bandwidth, the carrier frequency of a conventional narrow band transmitter signal. The other 10 common technique, referred to as direct sequence spread spectrum "DS-DSS," directly multiplies a conventional narrow band signal by the chip sequence. The chip rate is typically much higher than the data rate of the conventional narrow band signal. In both of these common spread spectrum techniques, a conventional narrow band signal is viewed as a carrier that is either frequency modulated or directly multiplied by the chip sequence. It is 15 appreciated that other types of spread spectrum systems include combinations of both FH-DSS and DS-DSS in one system.

Spread spectrum signals allow more than one transmission signal in the same frequency and time interval when each signal uses a different chip sequence. This technique is known as code division multiple access "CDMA." An example application of Direct 20 Sequence CDMA "DS-CDMA" is the Global Positioning System "GPS." The GPS system uses DS-CDMA to broadcast time and position data to receivers, which use such data to determine position and navigation information.

In a spread spectrum system, the conventional narrow band signal is spread by a PN code signal that has a wider bandwidth than the conventional narrow band signal. In order to 25 correctly restore the conventional narrow band signal, the demodulation PN code generated

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at the receiving side is synchronized to the modulation PN code generated at the transmitting side. Proper phase synchronization is typically achieved when the received spread spectrum signal is accurately timed in both its spreading PN code pattern position and its rate of chip generation. The phase synchronization process is preferably accomplished in two stages: an 5 initial synchronization process to find a synchronous phase, and a process to track the detected phase. Known techniques for initial synchronization depend upon both analog and digital sliding correlators, matched filters and other equivalent devices.

In a conventional matched filter spread spectrum receiver, the receiver includes a radio frequency "RF" section that receives the spread spectrum signal having a PN code 10 modulated therein. The receiver converts the received spread spectrum signal into an intermediate-frequency "IF" signal. An in-phase converter and a quadrature-phase converter convert the IF signal into an in-phase "I-channel" spread signal and a quadrature-phase "Q-channel" spread signal. A PN code sync device de-spreads the received PN code modulated from the spread spectrum signal by synchronizing a reference PN code with the received PN 15 code and maintaining the two codes in fine synchronism using, for example, a pair of correlators or a tracking loop based on a matched filter. A data demodulator demodulates the spread spectrum signal into the original baseband "narrow band" signal. Utilizing a matched filter has the advantage that the transmitted spread spectrum signal may be acquired relatively quickly even with relatively large initial errors between the locally generated PN 20 code and the received PN code.

Unfortunately, a problem associated with matched filters is that matched filters include register and summing circuits to despread a PN code from a spread spectrum signal. Conventional register and summing circuits use a significant number of multipliers and adders to perform the calculations necessary to despread the PN code. This increases the 25 amount of power used by the circuit and slows down the calculations. Accordingly, there is

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a need for a register and summing circuit that avoids the limitations of the prior art, has low power consumption, and is fast.

SUMMARY

A number of technical advances are achieved in the art, by implementation of an improved matched filter system for despreading a spread spectrum signal using a PN code. The improved matched filter system may be broadly conceptualized as a system that optimizes the number of multipliers and adders utilized by the system in despreading a spread spectrum signal using a PN code; thus lowering the power consumption of the improved matched filter system and increasing the speed at which the system despreads the spread spectrum signal using a PN code.

For example, an improved matched filter system that receives a spread spectrum signal may utilize a system architecture that recognizes that the same calculations are performed for the in-phase portion and the quadrature-phase portion of each signal sample of the spread spectrum signal, as well as for alternating pairs of signal samples. An implementation of the system architecture may include a switch and a multiplier in signal communication with the switch. The switch selects either the in-phase portion or the quadrature-phase portion of the spread spectrum signal, and the multiplier multiplies the selected portion of one of the signal sample with one of the PN code chips to obtain a product. The implementation may further include another multiplier coupled to the switch and an adder coupled to the first multiplier and the second multiplier. The second multiplier multiplies the selected portion of a second signal sample (which succeeds the first signal sample) with the PN code chip to obtain a second product. The adder then adds the first product with the second product to obtain a sum.

The improved matched filter system may also utilize a system architecture that recognizes that the same calculations are performed for pairs of signal samples. However,

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the spread spectrum signal comprises a plurality of signal sample pairs. Each pair of signal samples includes an even signal sample and an odd signal sample, and each signal sample has an in-phase portion and a quadrature-phase portion. An implementation of the system architecture may include a number of switches and multipliers. In its simplest form, the 5 implementation may include two switches and a multiplier. The first switch is coupled to the second switch and the multiplier is coupled to the second switch. The first switch selects either the in-phase portion or the quadrature-phase portion of the spread spectrum signal. The second switch selects either the even sample or the odd sample. The multiplier multiplies the selected portion of the selected sample of one signal sample pair with one PN 10 code chip to obtain a product.

The system may also include a second multiplier coupled to the second switch and an adder coupled to the first multiplier and the second multiplier. The second multiplier multiplies the selected portion of the selected sample of a second signal sample pair (which succeeds the first signal sample pair) with a second PN code chip (which succeeds the first 15 PN code chip) to obtain a second product. The adder then adds the first product with the second product to obtain a sum.

Other systems, methods, features and advantages of the invention will be or will become apparent to one with skill in the art upon examination of the following figures and detailed description. It is intended that all such additional systems, methods, features and 20 advantages be included within this description, be within the scope of the invention, and be protected by the accompanying claims.

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The invention can be better understood with reference to the following figures. The components in the figures are not necessarily to scale, emphasis instead being placed upon illustrating the principals of the invention. Moreover, in the figures, like reference numerals 5 designate corresponding parts throughout the different views.

FIG. 1 is a block diagram of an example implementation of a system utilizing a Doppler corrected matched filter in accordance with the invention.

FIG. 2 is a block diagram of an another example of system utilizing a Doppler corrected matched filter.

10 FIG. 3 is a block diagram of an example implementation of a matched filter shown in FIG. 1 and 2.

FIG. 4 is a block diagram of an example implementation of a Doppler generator shown in FIG. 3.

FIG. 5 is a state machine diagram for the state machine shown in FIG. 4.

15 FIG. 6 is a phasor representation of the state machine diagram shown in FIG. 5.

FIG. 7 is a logic diagram of one embodiment of the register and summing circuitry of the matched filter shown in FIG. 3.

FIG. 8 is a logic diagram of a second embodiment of the register and summing circuitry of the matched filter shown in FIG. 3.

20 FIG. 9 is a logic diagram of a third embodiment of the register and summing circuitry of the matched filter shown in FIG. 3.

FIG. 10 is a table comparing the calculations performed by the register and summing circuitry of FIG. 8 and the register and summing circuitry of FIG. 9.

FIG. 11 illustrates an implementation of the matched filter system in a network assisted environment.

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Reference will now be made in detail to the description of the invention as illustrated in the drawings. While the invention will be described in connection with these drawings, there is no intent to limit it to the embodiment or embodiments disclosed therein. On the contrary, the intent is to cover all alternatives, modifications, and equivalents included within 5 the spirit and scope of the invention as defined by the appended claims.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The invention is described for use with a spread spectrum matched filter with Doppler correction suitable for use in a radio frequency receiver. The Doppler corrected matched filter may serve a number of applications including use in spread spectrum or 10 Global Positioning System "GPS" radio frequency receivers. In a normal GPS navigation application, the Doppler corrected matched filter system may selectively output code phase information that allows a signal processing tracking loop to directly acquire prepositioning data for a particular GPS satellite. The Doppler corrected matched filter system is then utilized in support of reacquisition and anti-multipath operations. Additionally, in a single 15 fix application, the Doppler corrected matched filter system may provide the only data required because the signal processing channels are not employed.

1. SYSTEM ARCHITECTURE

Referring now in detail to the drawings in which the reference numerals indicate like parts throughout several views, FIG. 1 is a block diagram showing an example 20 implementation of a Doppler corrected matched filter system 100 utilizing a matched filter 102 in accordance with the invention. The Doppler corrected matched filter system 100 includes three sets of samplers 104, 106 and 108 (i.e., the samplers may selectively be latches), respectively, a limiter 110, an optional filter 112, the matched filter 102, and a mixer 114. The Doppler corrected matched filter system 100 also includes clock multiplier 25 116, frequency generator 118, carrier numerically controlled oscillator "NCO" and generator

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120, a code NCO and generator 122, a code generator 124, and a T20 offset measurement circuit 126.

The Doppler corrected matched filter system 100 may be utilized in various contexts, such as in communications or navigation applications. The Doppler corrected matched filter 5 system 100 is in signal communication with a conventional spread spectrum radio frequency "RF" receiver front end 128 and a signal processor 130. The Doppler corrected matched filter system 100 has an interface to an external bus 132 over which the Doppler corrected matched filter system 100 may receive commands from a controller 134 (for example, in a carrier command register set 136 and/or a code command register set 138) and provide 10 output results to the controller 134. The external bus 132 is in signal communication with a controller 134. The Doppler corrected matched filter system 100 may be integrated into a receiver system, or may constitute a separate device.

The controller 134 may selectively be any general-purpose processor such as an Intel XXX86, Motorola 68XXX or PowerPC, or other equivalent processor capable of running 15 software instructions (not shown) resident on the controller 134. Alternatively, a GPS-specific circuit or oriented device may selectively also be utilized. It is appreciated that the controller 134 may also be integrated into a signal semiconductor chip such as an Application Specific Integrated Chip "ASIC" or Reduced Instruction Set Computer "RISC," or may be implemented via a Digital Signal Processor (DSP) chip. Examples of GPS- 20 oriented devices include the "Scorpio 11577-11" digital integrated circuit produced by Conexant Systems, Inc., "GSP1 SiRFstar I" and "GSP2e SiRFstart II" architectures available from SiRF Technology, Inc., "MGPSCS-A1" and "MMC2003" from Motorola, Inc., and the "SAA1575HL" GPS baseband processor from Philips, Inc, or the equivalent.

The RF receiver front end 128 converts a received spread spectrum signal into an 25 intermediate-frequency "IF" signal and then converts the IF signal into an in-phase I signal

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and a quadrature-phase Q signal 140 which correspond to the real and imaginary parts of the received signal. For example purposes, the I and Q signals are each represented as 2-bit binary values in the range of -1, 0, and +1. It is appreciated that the -1 value is preferably represented as the 2's complement of the value 1. Thus, the 2-bit binary values would be 00, 01, and 11. The RF receiver front end 128 also provides a clock signal 142 to the Doppler corrected matched filter system 100 via the clock multiplier 116. In a GPS DS-CDMA system, the fundamental frequency F_0 is 10.23 MHz. This fundamental frequency is converted by the RF front end 128 to the clock signal 142 having a frequency $f = F_0 \frac{137}{128}$ (approximately 11 MHz). The frequency $f = F_0 \frac{137}{128}$ is then coupled 5 to the clock multiplier 116. The signal processor 130 also receives the I and Q signals 140 and clock signal 142 from the RF receiver front end 128, and may have control signals in signal communication with the RF receiver front end 128, in known fashion.

Examples of the RF front end 128 may selectively be a "Gemini/Pisces Monopack R6732-13" integrated circuit available from Conexant Systems, Inc., "GRF1 SiRFstarI" and 10 "GRF2i SiRFstarIIe" architectures available from SiRF Technology, Inc., "MGPSCS-A1" GPS Chipset, "PSRF111A" RF module, and/or "MRFIC1502" Integrated GPS down converter from Motorola, Inc., and/or the "UAA1570HL" GPS front-end receiver circuit from Philips, Inc, or the equivalent. The signal processor 130 may be, for example, the "Scorpio 11577-11" digital integrated circuit produced by Conexant Systems, Inc., "GSP1 15 SiRFstar I" and "GSP2e SiRFstart II" architectures available from SiRF Technology, Inc., "MGPSCS-A1" and "MMC2003" from Motorola, Inc., and the "SAA1575HL" GPS baseband processor from Philips, Inc, or the equivalent.

In an example implementation of the Doppler corrected matched filter system 100, input processing receives an input sample stream of data, reduces the sampling rate of the 20 data, and stores 20 milliseconds (ms) worth of the resulting data samples. In this example,

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the Doppler corrected matched filter system 100 reduces the data sampling rate to about 2.046 MHz and stores complex data samples, each represented by a three level I sample (i.e., $I = -1 + j0, 0 + j0$ and $1 + j0$) and a three level Q sample (i.e., $I = 0 - j, 0 + j0$ and $0 + j$). As a part of the sample rate reduction, the received samples go through a complex mixing process

5 to remove the $f = F_0 \frac{1}{8}$ (approximately 1.28 MHz), IF frequency, plus any desired offset

frequency due to an estimated error in the frequency standard or to average Doppler shift.

The 20 ms period during which the samples are taken is related to a T20 by means of an offset counter (not shown). It is appreciated that this relationship allows the correlation values output by the Doppler corrected matched filter system 100 to be related in time to the

10 code phase settings of the various signal processing channels in a signal processor such as signal processor 130. In particular, the Doppler corrected matched filter system 100 utilizes the stored samples multiple times to calculate the cross correlation values between the received samples and several combinations of PN codes and Doppler shifts. The results of these operations are then supplied to the controller 134 (which may be part of the signal

15 processor 130) via the external bus 132.

More particularly, in the Doppler corrected matched filter system 100, the clock multiplier 116 generates a $f = F_0 \frac{137}{32}$ (approximately 44 MHz) clock signal 144 from the input 11 MHz clock signal 142. The 44 MHz clock signal 144 is applied to the code NCO 122. The code NCO 122 generates a code clock 146 to re-sample the I and Q signals 140 in sampler 104. The code clock 146 sample frequency has a nominal rate of $f = 2F_0$ (approximately 20.46 MHz) that is modified by commands from the controller 134 via code command register 138 to account for estimated values of average Doppler and IF error. The re-sampled data is then applied to the second sampler 106 via signal path 148. The second sampler 106 is also clocked by code clock 146.

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The 44 MHz clock signal 144 is also applied to the frequency generator 118 which generates output signals of frequencies of $f = 2F_0$, (approximately 20.46 MHz) 150; $f = F_0 \frac{1}{8}$ (approximately 1.28 MHz) 152; and clock 154 at $f = F_0 \frac{1}{30}$ (approximately 341 kHz). The clocks 152 and 154 preferably have selectable rates of $f = F_0 \frac{1}{2}$ (approximately 5.115 MHz) and $f = F_0 \frac{1}{60}$ (approximately 171 kHz). These selectable rates accommodate a wider range of NCO frequencies which address systems with possibly less accurate fundamental frequency sources.

The signal processor 130 provides a T20 sync input 156 that may be synchronized to a data capture start signal 158 of the matched filter 102. When the controller 134 commands the matched filter 102 to capture data samples, the matched filter 102 provides a data capture start signal 150 to the T20 offset measurement circuit 126. The T20 offset measurement circuit 126 counts the 44 MHz clock cycles 144 until there is a transition in the T20 sync input 156. After the data capture is complete, the controller 134 reads the offset counter value from the T20 offset measurement circuit 126 via the external bus 132. The offset measurement allows the controller 134 to use the subsequent matched filter 102 code correlation outputs to initialize tracking loops in the signal processor 130.

The received samples in the second sampler 106 are re-sampled at $f = 2F_0$ (approximately 20.46 MHz), via clock signal 146, from the code NCO and generator 122 in a manner similar to a normal DS-CDMA signal processing channel. The mixer 114 performs a complex multiplication of the output signal 160 of the carrier frequency NCO and generator 122 and the output signal 165 of the second sampler 106. The carrier frequency NCO and generator 122 produces the output signal 160 at the IF frequency, $f = F_0 \frac{1}{8}$

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(approximately 1.28 MHz), plus an estimated frequency and average Doppler error. The mixer 114 preferably utilizes the a 7 level (i.e., -3 to 3 and -3j to 3j for I and Q) mixing scheme (similar to a conventional signal processing channel), resulting in an output range for each of the I and Q signals of -6 to +6 and -6j to +6j [i.e., $(1+j)(3-3j) = 6$, $(-1-j)(3-3j) = -6$, $(1+j)(3+3j) = 6j$, $(1-j)(3-3j) = -6j$, etc.], represented in 8 bits (i.e., 4 bits real and 4 bits imaginary). The output signal 164 of the mixer 114 stage may then be applied to the optional anti-aliasing filter 112 to limit the bandwidth of the output signal 164 to no more than twice the sampling rate of the third sampler 108 downstream from the filter 112. The filter 112 preferably provides a sliding average of 20 of the input samples to the filter 112.

10 The processed signal 166, from the either the optional filter 112 or the mixer 114 (same as output 164 if from mixer 114), is then applied to the limiter 110 which limits the range of binary values to -1, 0, and +1, represented in 2 bits each for the I and Q signals, to reduce the amount of data stored for 20 ms of the signal samples. The limited, mixed signal 168 is then re-sampled through the third sampler 108 at a frequency, $f = F_0 \frac{1}{5}$,

15 (approximately 2.046 MHz) with a signal 170 from the code frequency NCO and generator 122 to reduce the amount of data stored for the 20 ms of signal samples. The output 172 of the third sampler 108 is input into the matched filter 102. A separate code generator 124 provides a desired PN code 174 "chip sequence" to the matched filter 102 (described in further detail below). It is appreciated that the provision of both a carrier NCO/mixer and a 20 code NCO/sampler allows independent correction for a pure frequency shift in the former and of a Doppler shift to both carrier and code in the latter.

FIG. 2 is a block diagram of another example implementation of a Doppler corrected matched filter system 100. In this example, the incoming I and Q signals 140 (from the RF front end 128 in FIG. 1) are re-sampled through the first sampler 104 at F_0 and then subjected to 5 level (i.e., -2 to 2 and -2j to 2j for I and Q) mixing by mixer 200. Limiting is shown

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occurring after the second sampler 202 at limiter 204. An alternative approach is shown in dotted outline. In this alternative approach, a filtering operation (through two summing registers 206 for the I channel and 208 for the Q channel) reduces the sample rate by a factor of ten, rather than re-sampling by means of the second sampler 202. It is appreciated that the 5 net effect of the filtering is to reduce the sample rate and correspondingly the size of a sample storage device, while avoiding the loss due to sample rate reduction without the appropriate bandwidth limiting beforehand. This implementation may be preferable when code phase measurements at the output of the matched filter 102 are to be interpolated for improved resolution.

10 2. Matched Filter Processing

Once the received samples are re-sampled and limited, they are stored in the matched filter 102 for repeated processing. FIG. 3 is an example block diagram of the matched filter 102 in accordance with the invention. In this example implementation, the sample signals 172, FIG. 1, are converted by a serial to parallel converter 300, FIG. 3, and stored in a sample 15 storage device 302. The sample storage device 302 may selectively be a 16-bit wide random access memory "RAM" device. With 4-bit complex (i.e., 4-bit for the real I channel and 4-bit for the imaginary Q channel) input samples, the data may selectively be stored as 4 samples for each 16-bit word.

It is appreciated that the 20 ms of data samples are stored in the sample storage 20 device 302. However, the data is processed in 1 ms segments, corresponding to the period of a GPS PN code. Each one millisecond period will have 2046 4-bit complex (i.e., 1023 4-bit real I channel and 1023 4-bit imaginary Q channel) signal samples and 1023 PN code chips, or 2 received samples per PN code chip. The PN chips may selectively be loaded serially into a PN code register 304 via signal path 306 (that may selectively be 174 from FIG. 1) and 25 the PN code is shifted through the PN code register 304 for each code phase via shift path

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308. As each one millisecond segment from the sample storage device 302 is about to be processed, it is pre-multiplied by a Doppler shifting circuit (not shown) and then stored in a signal sample register 310. The Doppler shifting circuit comprises a Doppler generator 312 and a complex mixer 314.

5 The complex mixing operation is similar to the mixing shown in FIG. 1. In FIG. 1, the mixing shifts the code spectrum to near zero frequency offset. In FIG. 3, however, the mixing shifts the spectrum by a relatively small amount, roughly over a range of about 8000 Hz. It is appreciated that there are no more than about 8 cycles of complex local oscillator error in a one millisecond segment of 1023 samples.

10 It is appreciated that the value of 8000 Hz of fine Doppler correction is not a hard limit. The particular frequency range depends on the basic signal-to-noise ratio of the input samples and the margin associated with this value. The matched filter Doppler correction is selectively applied to the complex phase of the stored samples. The Doppler of the PN code on the envelope of this phase is not corrected in the matched filter because it is corrected in

15 the processing that is done before the samples are stored by means of the re-sampling from

$$f = F_0 \frac{137}{32} \text{ (approximately 44 MHz)} \text{ down to } f = 2F_0 \text{ (approximately 20.46 MHz)}$$

controlled by the NCO frequency setting.

In this example, it is appreciated that both the PN code loading into the PN code register 304 and the Doppler mixing in mixer 314 occur faster than "real time." Preferably, a 20 clock such as $f = 2F_0$ would be used. Thus, once data samples are loaded in "real time," subsequent processing may selectively be faster than "real time."

When both the PN code and the Doppler-shifted signal samples are loaded into the PN code register 304 and signal sample register 310, respectively, the correlation process begins. Each complex signal sample is multiplied by its corresponding PN code chip. There

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are two samples for each code chip, or a pair of half chip spaced correlations for every two samples. All 2046 multiplications may selectively be done at once, since the process is a sign inversion. The resulting products are then input to an adder tree for summation and output as one millisecond of complex coherent integrations. A product/adder circuit 316

5 performs these functions.

The output of the product/adder circuit 316 is applied to a conventional envelope generator 318, which in the present example calculates the square root of the sum of squares (i.e., the envelope generator 318 may selectively be a square root circuit). The conventional envelope generator 318 determines the envelope of the one millisecond waveform. It is

10 appreciated that this calculation removes any problems associated with signal inversions due to the 50 Hz data modulation on the GPS signal.

The I and Q outputs 320 are then further processed by non-coherently combining their envelope through a mixer 322 with any prior one millisecond correlations for this same PN code phase, previously stored in a storage device 324. A complete cycle of 20

15 summations is stored in the storage device 324 for each 20 ms PN code cycle. The storage device 324 may selectively be a RAM or other equivalent memory element.

After each such pair of half chip spaced correlations, the PN code register 304 is cyclically shifted by 1 chip, via shift path 308, and the process is repeated. After 1023 such shifts, all 2046 correlations are computed for the current one millisecond segment. At that

20 point, the next 1 ms segment from the sample storage device 302 is Doppler multiplied and loaded into the signal sample register 310. Thus, the process is repeated for each of the 20 one millisecond segments stored in the sample storage device 302. After 20 ms have been processed, the output storage device 324 contains 2046 correlation values. This procedure may selectively be repeated for as many combinations of PN code and Doppler shift as

25 desired.

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The final correlation values in the output storage device 324 may be selectively available over the external bus 132 for further processing by other systems. The Doppler corrected matched filter system 100, FIG. 1, may then generate an interrupt to an external signal processor, which may selectively read out the results of the correlation process. As an 5 example, the desired result may be the maximum value and its code phase (located in the storage device 324). However, in other examples, additional information may be required that is different for various applications. For example, samples adjacent to the maximum value may be utilized to provide information about the likelihood of the peak being a cross correlation signal. Smaller peaks at earlier phases may indicate a partially blocked line-of-sight path. The three or four adjacent peaks of a maximum peak may be employed to better 10 define the optimum location of the true correlation peak. In an another example, the Doppler corrected matched filter system 100 may provide a specialized search function 326 that automatically provides the largest correlation value or values (i.e., 8 largest peaks) and the corresponding location (code phase) in the array of 2046 non-coherent sum values after all 15 twenty segments have been processed.

FIG. 4 is a block diagram of an example implementation of a Doppler generator 312 shown in FIG. 3. The Doppler generator 312 includes a register 400 coupled to an adder 402, an accumulator register 404, and a state machine 406. FIG. 5 is a state machine diagram for the state machine 406 shown in FIG. 4. The output of the Doppler generator 312 is a multi-level (i.e., 3 levels) quantized complex phasor (i.e., $\cos\theta + j\sin\theta$ where θ is the 20 phase of the phasor). The phase is quantized to 45 degrees. FIG. 6 is a phasor representation of the state machine diagram shown in FIG. 5.

In operation, a desired Doppler value is written over the bus 408, FIG. 4 (which may be in signal communication with complex mixer 314), into the register 400. The magnitude 25 is added to the accumulator 404 at the same rate that memory elements such as words

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containing four complex samples are read from the sample storage device 302, FIG. 3. Whenever the accumulator 404 has an overflow condition, the state machine 406 is advanced or retarded one state, depending on the value of the sign bit. The overflow condition represents 45 degrees of accumulated Doppler. In an another example implementation, the 5 Doppler generator 312 may be a lookup table (i.e., in RAM or read only memory "ROM") with stored pre-computed Doppler shift correction values.

3. Register and Summing Circuitry of the Matched Filter

FIG. 7 illustrates a logic diagram for a register and summing circuitry 700 in a matched filter. The register and summing circuitry 700 is used to despread a PN code from a 10 spread spectrum signal in a matched filter. In this embodiment, a basic cell 702 is defined as including: two pairs 704, 706 of I and Q latches for storing input I and Q data samples each represented as two or three bit quantities that may have the values -1, 0 and +1 (or -2, -1, 0, 1, or 2 for three bits); corresponding one bit multipliers 708 for applying the PN chips as one bit quantities that have the values -1 and +1, hence, the multipliers 708 have the effect of 15 changing the sign bit of the I and Q data values; a corresponding 1 bit shift register PN chip stage 710; and an odd-even switch 712 between cells 702 that allows each PN chip stage 710 to be applied to successive pairs of I and Q latches without shifting the PN code each time, thus saving power (i.e., this feature saves 1023 shift register stages and the power associated 20 with making extra shifts).

The outputs of the multipliers 708 are coupled to an adder tree 714, which hierarchically adds all of the 2046 stages until final I and Q sums are output. The example adder tree 714 shown has 14 bit adders as the final stage. The width of the adders may selectively be reduced after a few stages. The register and summing circuitry is implemented in relatively few gates because the data widths involved in the basic cell 702 are small.

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FIG. 8 illustrates a second embodiment for a register and summing circuitry 800 in a matched filter. A basic cell 802 in this embodiment includes: four pairs 804, 806, 808, 810 of I and Q latches for storing input I and Q data samples; corresponding I-Q switches 812 between the I and Q latches 804, 806, 808 and 810; one bit multipliers 814 for applying the 5 PN chips; a corresponding 1 bit shift register PN chip stage 816; and two odd-even switches 818 that allow each PN chip stage 816 to be applied to successive pairs of I and Q latches without shifting the PN code. The register and summing circuitry 800 of FIG. 8 recognizes that the same calculations are performed for both the I and Q samples. Accordingly, FIG. 8 includes I-Q switches 812 to reduce the number of multipliers 814 to half the number of 10 multipliers 708 shown in FIG. 7.

FIG. 9 illustrates a logic diagram for a third embodiment of the register and summing circuitry 900 of the matched filter 102 shown in FIG. 3. The basic cell 902 includes: two pairs 904, 906 of I and Q latches for storing input I and Q data samples; corresponding I-Q switches 908 between the I and Q latches 904, 906; an odd-even switch 910 between the I-Q 15 switches 908; a multiplier 912; and a 1 bit shift register PN chip stage 914. The outputs of the multipliers 435 are coupled to an adder tree 916.

As shown in FIG. 9, the in-phase/quadrature-phase portion of the spread spectrum signal and the odd/even signal sample are selected prior to reaching the multiplier 912. In the circuitry 800 of FIG. 8, the odd/even signal sample is selected after the in-phase/quadrature-phase portion is multiplied by the PN code chip. Accordingly, the circuitry 20 900 of FIG. 9 uses half the number of multipliers as the circuitry 800 of FIG. 8.

FIG. 10 illustrates a table comparing the output A_n 1000 of the basic cell of FIG. 9 with the output A_n 1002 of the basic cell of FIG. 8. "C" 1004 represents the PN code chip currently being processed in the basic cell. There are two types of switches in each of the 25 basic cells. In the table, an "O" indicates that the odd-even switch is in the odd state, an "E"

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indicates that the odd-even switch is in the even state, an "I" indicates that the I-Q switch is in the in-phase mode and a "Q" indicates that the I-Q switch is in the quadrature-phase mode. Thus, "EQ" in column 1006 identifies switches set to process "even" and "Q samples." Column 1008 identifies the combination of the outputs 1000 of the cells of FIG. 9 by row numbers 1010 which is equivalent to the output 1002 of the cells of FIG. 8. Accordingly, the adder tree 916 is designed to equate the register and summing circuitry 900 of FIG. 9 to the register and summing circuitry 800 of FIG. 8. Because the circuitry 900 in FIG. 9 uses half the number of multipliers as the circuitry 800 in FIG. 8, circuitry 900 in FIG. 9 requires less power than the circuitry 800 of FIG. 8.

10 4. PROGRAMMING AND CONTROL

The Doppler corrected matched filter system 100 is envisioned as an independent subsystem that is controlled by a processor such as the controller 134 or other equivalent processor. The degree of autonomy required of the Doppler corrected matched filter system 100 depends primarily on its speed of operation. If the time required to search one code/Doppler bin is on the order of 10-20 ms, then the most likely mode of operation would be for the controller 134 to issue a command to do a load or search, have the Doppler corrected matched filter system 100 execute that command, and then have the controller 134 collect the results and issue a command for the next operation, if necessary. Alternatively, if the Doppler corrected matched filter system 100 is operated at very high speed, such as the 20 5000 one-millisecond segment searches per second mentioned above, it would likely be required that a sequence of commands be issued and that the Doppler corrected matched filter system 100 have an automated method, such as a direct memory access "DMA" capability, of delivering results to the controller 134.

After the controller 134 has read out all of the data required for the particular 25 operation it is performing with the Doppler corrected matched filter system 100, the

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controller 134 may issue the next command, if necessary. Thus, the Doppler corrected matched filter system 100 may operate asynchronously, as rapidly as the controller 134 may process its output results.

When the invention is used to acquire the signal of a GPS satellite, the objective for 5 the Doppler corrected matched filter system 100 during initial acquisition is to get enough satellites in track to support navigation within one second. Because of the inexpensive frequency standard technology used, this may require searching 10-20 Doppler bins until the first satellite is acquired. In cold start conditions (where some system initialization information is lacking), it may be necessary to search for 2-3 satellites before a visible 10 satellite is selected. Therefore, it is necessary to be able to search 50 to 100 Doppler bins per second to meet this objective. This search rate is consistent with allowing a current-technology microprocessor to control the Doppler corrected matched filter system 100 one command at a time.

Accordingly, under these assumptions, the command set for the Doppler corrected 15 matched filter system 100 may be relatively simple. The following example commands may be implemented:

- X LOAD SIGNAL SAMPLES: At the beginning of the next T20 interval, the Doppler corrected matched filter system 100 would begin loading 20 ms of signal samples.
- 20 X INPUT FREQUENCY: A register is required to specify the nominal frequency shift to use while the signal samples are loaded. Assuming reuse of the carrier and code NCO and generation circuits 120, 122 and 124, FIG 1, this interface may be based on those designs.

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- X EXECUTE SEARCH: The Doppler corrected matched filter system 100 would immediately execute a correlation search based on the programmed search parameters.

Search parameter registers could be programmed to store the following values:

- 5 X DOPPLER SHIFT: This is a Doppler shift applied to the stored signal as each 1 ms segment is loaded into the signal sample register 310. For example, there may be on the order of 16 or so Doppler values, representing shifts of $750*n$ Hz, where $n=0$ though 15.
- 10 X PN CODE: This register would likely be used in association with the existing code generator 124. The new function would be to inform the Doppler corrected matched filter system 100 that a new PN code is required, so that the code would be generated and loaded into the code register 304 for use in the next, and subsequent, correlation searches.

5. Program Implementation

15 For performance purposes with current technology, the invention is preferably implemented in dedicated circuitry. However, the functions performed by the invention may also be implemented in generalized programmable circuitry capable of generating the following steps:

- 20 (1) Receive and store an input sample of a complex signal to be Doppler shift corrected and correlated to a code signal; optionally limit the received complex signal in value range and/or sampling frequency.
- (2) Complex mix at least a portion of the stored input sample with a Doppler shift correction value.
- (3) Compute the complex products of the mixed portion of the stored input sample with a 25 current code phase of the code signal.

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- (4) Sum the computed complex products as a current complex integration value.
- (5) Compute, such as generating an envelope, (and normally store) the square root of the sum of the squares of the current complex integration value.
- (6) Shift the code signal to a next current code phase.
- 5 (7) Repeat steps (3) through (6) for the current code phase of the code signal.
- (8) Output the code phase and magnitude of the stored computed square root value having the largest magnitude as an indication of correlation between the input sample and the code signal, corrected for Doppler shift.

The following is an example pseudo-code version of one example implementation of
10 a matched filter 102 in accordance with the invention:

```
// Matched Filter Algorithm Pseudo-code
// This version assumes that the samples are loaded with the
// digital IF Fo/8 plus the nominal estimated frequency error
// already removed. The complex spectrum is then centered
15 // near zero Hz. Further complex frequency shifts will be made
// to search other Doppler bins. The IF has to be removed before
// the sample rate is reduced from 20/Tca to 2/Tca. The analog
// bandwidth is a little too wide for this sampling rate. It has
// to be verified that the PN waveform is as tolerant as expected
20 // to the resulting aliasing.
// ***** Load the matched filter *****
// This operation is real time, in the sense that the samples are
// being created by a clock that has to sample uniformly in time.
// So, these samples have to be stored as fast as they are received.
25 // Subsequent processing in the MF can be non-real time (either
// faster or slower).
#define SAMPLES_PER_MS (2046) // Sampling at 2/Tca = 2.046 MHz
#define NUMBER_OF_MS (20)
// The signal samples are complex values (I,Q). Each component,
30 // in-phase or quadrature, can take on three values: -1, 0, +1. In the
// hardware before the MF, these samples are represented by two bits each
// for I and Q
int s[NUMBER_OF_MS][SAMPLES_PER_MS][2];
int i,j;
35 for( i = 0 ; i < NUMBER_OF_MS ; i++ )      // each one ms segment
{
    for( j = 0 ; j < SAMPLES_PER_MS ; j++ )    // each complex sample in the ms
    {
        s[i][j][0] = Get_I_Phase_Sample(); // three-valued, two bit I sample
        s[i][j][1] = Get_Q_Phase_Sample(); // three-valued, two bit Q sample
40 }
```

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```

        }
    }

// ***** Load GPS PN Code *****
5      // GPS PN codes could be generated as needed by code generator (re-use design
// from signal processor channels). Alternatively, they could be stored in a ROM.
// Each chip is one bit representing the values -1 and +1.
#define CHIPS_IN_CODE (1023)      // periodic length of GPS PN codes
#define NUMER_OF_CODES (32)       // number of GPS codes (ignoring
                             pseudolites
10     // and WAAS codes)
int c[NUMER_OF_CODES][CHIPS_IN_CODE]; // Assume ROM storage
notation.

// ***** Load Doppler Signal *****
15     // The notation here assumes that the complex signals to mix the various Doppler
values
// to dc are stored in a ROM as complex values. That is not a likely implementation,
// but makes the math easier to visualize. The values are assumed to be 5 level signals
// like the normal signal processing channels use. Most likely, the generator used
// in the normal signal processing channels could be used as a starting point. Simpler
20     // implementations using two level quantization (-1,+1) are likely.
#define NUMBER_OF_DopplerS (16)
int d[NUMBER_OF_DopplerS][SAMPLES_PER_MS][2];
for( code = 0 ; code < NUMER_OF_CODES ; code++ ) // process each code
{
25     for( dop = 0 ; dop < NUMBER_OF_DopplerS ; dop++ ) // process each Doppler
shift
{
    for( seg = 0 ; seg < NUMBER_OF_MS ; seg++ ) // process each ms
    {
        for( sample = 0 ; sample < SAMPLES_PER_MS ; sample++ ) // do Doppler
shift while loading 1 ms signal register
        {
            s_1ms[sample][RE] = d[dop][sample][RE] * s[seg][sample][RE] -
d[dop][sample][IM] *
30             s[seg][sample][IM];
            s_1ms[sample][IM] = d[dop][sample][IM] * s[seg][sample][RE] +
d[dop][sample][RE] *
                     s[seg][sample][IM];
        }
        for( shift = 0; shift < CHIPS_IN_CODE ; shift++ ) // process each phase shift
of the code
        {
            half_shift = 2 * shift;
40
45        for( half_chip = 0 ; half_chip < 2 ; half_chip++ ) // two samples per chip
        {
// ***** Run the Matched Filter *****
// This version assumes that as each segment is loaded from RAM into a 1 ms long
latch
50        // for correlation with the PN code, the Doppler signal is applied.

```

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```

int code; // which pn code is being processed
int sample; // which sample is being processed
int shift; // which of the code phases is being processed
int half_shift; // because there are two samples per chip
5 int seg; // which one ms signal segment is being processed
int dop; // which Doppler bin is being processed
int chip; // which chip is being processed
int r_ms; // ms accumulator, real part
int i_ms; // ms accumulator, imaginary part
10 int sum_20ms[SAMPLES_PER_MS]; // 20 ms non-coherent accumulators
int s_1ms[SAMPLES_PER_MS][2]; // Current 1 ms of Doppler shifted signal
#define RE (0)
#define IM (1)
// here we are showing that all codes, Dopplers and phase shifts are processed.
15 // We may want to be able to select a sub-range, list, or single one of these.
// There are probably some command registers to specify ranges & modes of
operation.
    if(seq == 0) // zero the 2046 non-coherent 20 ms integrator on first
segment
20    {
        sum_20ms[half_shift + half_chip] = 0;
    }
    r_20ms = 0; // zero the coherent 1 ms integrators
    i_20ms = 0;
25
    for( sample = 0 ; sample < SAMPLES_PER_MS ; sample++ ) // form 1
ms sums
    {
        chip = (sample + half_chip) / 2; // stays the same for two consecutive
samples
        // The sum can change only by -2, -1, 0, +1, or +2 at each pass
        // There is a way to use 5 level (rather than 3 level) Doppler signals and
still have only
        // these change values. This results in less implementation loss of C/No.
30        // The last half chip of the last sample might just be skipped, if it helps.
        r_ms += c[code][(shift+chip)%CHIPS_IN_CODE] * ( s_1ms[sample][RE] );
        i_ms += c[code][(shift+chip)%CHIPS_IN_CODE] * (
        s_1ms[sample][IM] );
    }
40
    // The sqrt of the sum of squares (envelope) can be approximated by:
    // max_abs = MAX( |r_ms| , |i_ms| );
    // min_abs = MIN( |r_ms| , |i_ms| );
    // sum_20ms = max_abs + min_abs/2;
    sum_20ms[half_shift + half_chip] += sqrt( r_ms * r_ms + i_ms * i_ms ); // exact
45    value of envelope
}
} // end of half chip
} // end of code shift
} // end of 1 ms segment
50
// The 20 ms second sums for this code and Doppler are complete.
//

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```
// Alternatives at this point include
// 1. Interrupt processor to inspect 20 ms sums
//   (a lot of throughput, but might want in case of limited search).
// 2. Hardware search for N largest values and their locations; store for processor.
5      // 3. Hardware search for largest value and its location. Store for processor. May not
be adequate.
// 4. Store every value and location above a threshold. Store for processor.
// 5. Hardware search for largest value. Store value and location for processor.
Interrupt processor and
10     // halt the MF until re-enabled by processor. Then continues with next search.
// Below shows illustration for largest value.
    MaxLoc = -1;
    MaxVal = -1;
for( sample = 0 ; sample < SAMPLES_PER_MS ; sample++ )
15     {
        if( sum_20ms[sample] > MaxVal )
        {
            MaxVal = sum_20ms[sample];
            MaxLoc = sample;
20        }
    }
// Interrupt processor. Processor has until next start of search to get results.
// Might want to have a mode that suspends until interrupt is acknowledged.
// This would be useful if the processor were going to search the 20 ms sums itself or
25     // extract some other data.
Interrupt(MF_Complete);
} // end of one Doppler bin
} // end of one pn code choice
MF_Idle(); // Go to sleep. No clocks, no/low power.
30
The software, which comprises an ordered listing of executable instructions for
implementing logical functions, may selectively be embodied in any computer-readable
medium for use by or in connection with an instruction execution system, apparatus, or
device, such as a computer-based system, processor-containing system, or other system that
35 may selectively fetch the instructions from the instruction execution system, apparatus, or
device and execute the instructions. In the context of this document, a "computer-readable
medium" is any means that may contain, store, communicate, propagate, or transport the
program for use by or in connection with the instruction execution system, apparatus, or
device. The computer readable medium may selectively be, for example but not limited to,
40 an electronic, magnetic, optical, electromagnetic, infrared, or semiconductor system,
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apparatus, device, or propagation medium. More specific examples "a non-exhaustive list" of the computer-readable medium would include the following: an electrical connection "electronic" having one or more wires, a portable computer diskette (magnetic), a RAM (electronic), a read-only memory "ROM" (electronic), an erasable programmable read-only 5 memory (EPROM or Flash memory) (electronic), an optical fiber (optical), and a portable compact disc read-only memory "CDROM" (optical). Note that the computer-readable medium may even be paper or another suitable medium upon which the program is printed, as the program can be electronically captured, via for instance optical scanning of the paper or other medium, then compiled, interpreted or otherwise processed in a suitable manner if 10 necessary, and then stored in a computer memory.

6. IMPLEMENTATION IN NETWORK ASSISTED ENVIRONMENT

The Doppler corrected matched filter system 100 of the present invention may be incorporated in a positioning system that includes satellites and/or pseudolites (base stations) to triangulate the position of a receiver. FIG. 11 illustrates an example implementation of 15 the matched filter system 100 in a network assisted environment. FIG 11 shows a radio frequency receiver, in the form of a wireless device 1100, in signal communication with a stationary communication device 1102 (such as a base station or other network communication device) via signal path 1104. The wireless device 1100 receives signals from a number of satellites 1104, 1106 and 1108 via signal paths 1110, 1112 and 1114, respectively, and the stationary communication device 1102 receives signals from the 20 satellites 1104, 1106 and 1108 via signal paths 1116, 1118 and 1120, respectively. The wireless device 1100 includes an RF front end 1122 (similar to RF front end 128 in FIG. 1), the matched filter system 100, FIG. 11, and a radio module 1124.

In FIG. 11, a network 1126 is used to assist the wireless device 1100 to find the 25 signals from the satellites 1104, 1106 and 1108. The stationary communication device 1102

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is part of the network 1126 and includes a satellite positioning system receiver 1128 that receives satellite data messages or signals from the satellites 1104, 1106 and 1108. The stationary communication device 1102 is assumed to receive the signal approximately error free because it will have a clear view of the sky and will not have any obstructions blocking 5 the signals. In the network 1126, there may be numerous devices similar to the stationary communication device 1102. For convenience only, one stationary communication device 1102 is shown; however, it is appreciated that the following description is equally valid with multiple stationary communication devices. Additionally, only three of the approximately 12 available satellites are shown.

10 The geographic position of a wireless device may be calculated once a sufficient number of satellite signals are received at the wireless device. United States Patent No. 5,812,087 entitled "Method And Apparatus For Satellite Positioning System Based Time Measurement," issued to Norman F. Krasner on September 22, 1998, which is incorporated by reference, describes a method and apparatus for measuring time related to satellite data 15 signals in satellite positioning systems. The measured time is used to calculate the position of the wireless device. U.S. Patent No. 5,812,087 discloses the method and apparatus for establishing receiver timing at the wireless device by having a GPS receiver of the wireless device form an estimate of a portion of the satellite data message and transmit the estimate to a base station. The base station compares this estimate with a record of the satellite data 20 signals received from another GPS receiver at the base station. The comparison determines which portion of the base station's data most closely matches the data transmitted by the wireless device and the result of the comparison is transmitted back to the wireless device for reference. The time measurements may also be implemented in the system described in U.S. Patent No. 5,945,944, entitled "Method And Apparatus For Determining Time For GPS

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Receivers," issued to Norman F. Krasner on August 31, 1999, which is incorporated by reference.

U.S. Patent No. 5,945,944 discloses a method and apparatus of determining the time for a global positioning system receiver. Timing signals derived from a communication system, such as cellular phone transmission signals, are received by a GPS receiver and decoded to provide accurate time information. The timing signals may be in the form of synchronized events marked by timing indicators, or as system time information. The timing signals in combination with satellite position signals received by the GPS receiver are used to determine the position of the GPS receiver. The time measurements may also be implemented in an obstructive environment by the system described in U.S. Patent No. 5,831,574, entitled "Method And Apparatus For Determining The Location Of An Object Which May Have An Obstructed View Of The Sky," issued to Norman F. Krasner on November 3, 1998 and U.S. Patent No. 6,016,119, entitled "Method And Apparatus For Determining The Location Of An Object Which May Have An Obstructed View Of The Sky," issued to Norman F. Krasner on January 18, 2000, which are both incorporated by reference.

U.S. Patent No. 5,831,574 discloses a positioning sensor that receives and stores a predetermined record length of positioning signals while in a fix position located such that the positioning sensor can receive positioning signals. Thereafter, the stored positioning signals are processed to determine the geographic location of the fix position. The fix position may correspond to a location of an object of interest or it may be in a known location relative to the position of the object, in which case once the geographic location of the fix position has been computed, the geographic location of the object can be derived. The positioning sensor includes a Snapshot GPS receiver which may collect and process GPS signals transmitted by GPS satellites using fast convolution operations to compute

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pseudoranges from the GPS satellites to the fix position. Alternatively, these computations may be performed at a basestation. The computed pseudoranges may then be used to determine the geographic location of the fix position. The positioning sensor may be equipped with a depth sensing element, such as a pressure sensor, which allows a 5 determination of the depth of a submerged object to be made. The positioning sensor may further be equipped with signal detecting means for determining when the positioning sensor is in the fix position.

U.S. Patent No. 6,016,119 discloses a positioning sensor which receives and stores a predetermined record length of positioning signals while in a fix position located such that 10 the positioning sensor can receive positioning signals. Thereafter, the stored positioning signals are processed to determine the geographic location of the fix position. The fix position may correspond to a location of an object of interest or it may be in a known location relative to the position of the object, in which case once the geographic location of the fix position has been computed, the geographic location of the object can be derived. 15 The positioning sensor includes a Snapshot GPS receiver which may collect and process GPS signals transmitted by GPS satellites using fast convolution operations to compute pseudoranges from the GPS satellites to the fix position. Alternatively, these computations may be performed at a basestation. The computed pseudoranges may then be used to determine the geographic location of the fix position. The positioning sensor may be 20 equipped with depth sensing means, such as a pressure sensor, which allows a determination of the depth of a submerged object to be made. The positioning sensor may further be equipped with signal detecting means for determining when the positioning sensor is in the fix position.

After processing by the cancellation system, the wireless device may make the time 25 measurements based on the system described in U.S. Patent No. 5,884,214, entitled "GPS

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Receiver And Method For Processing GPS Signals," issued to Norman F. Krasner on March 16, 1999, which is incorporated by reference. U.S. Patent No. 5,884,214 discloses a global positioning system (GPS) receiver having first circuitry for receiving and processing pseudorandom sequences transmitted by a number of GPS satellites. The first circuitry is 5 configured to perform conventional correlation operations on the received pseudorandom sequences to determine pseudoranges from the GPS receiver to the GPS satellites. The GPS receiver also includes second circuitry coupled to the first circuitry. The second circuitry is configured to receive and process the pseudorandom sequences during blockage conditions. The second circuitry processes the pseudorandom sequences by digitizing and storing a 10 predetermined record length of the received sequences and then performing fast convolution operations on the stored data to determine the pseudoranges. The GPS receiver may have a common circuitry for receiving GPS signals from in view satellites and downconverting the RF frequency of the received GPS signals to an intermediate frequency (IF). The IF signals are split into two signal path, a first of which provides the conventional correlation 15 processing to calculate the pseudoranges. During blockage conditions, the IF signal is passed to the second signal path wherein the IF signals are digitized and stored in memory and later processed using the fast convolution operations to provide the pseudoranges. Alternative arrangements for the two signal paths include separate downconverters or shared 20 digitizers. One embodiment provides both signal paths on a single integrated circuit with shared circuitry executing computer readable instructions to perform GPS signal processing appropriate to the reception conditions.

Additionally, the wireless device may make the time measurements based on the system described in U.S. Patent No. 5,781,156, entitled "GPS Receiver And Method For Processing GPS Signals," which is incorporated by reference. U.S. Patent No. 5,781,156 discloses a GPS receiver in one embodiment which includes an antenna which receives GPS 25

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- signals at an RF frequency from in view satellites; a downconverter coupled to the antenna for reducing the RF frequency of the received GPS signals to an intermediate frequency (IF); a digitizer coupled to the downconverter and sampling the IF GPS signals at a predetermined rate to produce sampled IF GPS signals; a memory coupled to the digitizer storing the 5 sampled IF GPS signals (a snapshot of GPS signals); and a digital signal processor (DPS) coupled to the memory and operating under stored instructions thereby performing Fast Fourier Transform (FFT) operations on the sampled IF GPS signals to provide pseudorange information. These operations typically also include preprocessing and post processing of the GPS signals. After a snapshot of data is taken, the receiver front end is powered down.
- 10 The GPS receiver in one embodiment also includes other power management features and includes, in another embodiment, the capability to correct for errors in its local oscillator which is used to sample the GPS signals. The calculation speed of pseudoranges, and sensitivity of operation, is enhanced by the transmission of the Doppler frequency shifts of in view satellites to the receiver from an external source, such as a basestation in one 15 embodiment of the invention.

- Additionally, an example implementation of the time measurement utilizing the assistance of a base station may be implemented in the system described in U.S. Patent No. 5,874,914, entitled "GPS Receiver Utilizing A Communication Link," issued to Norman F. Kasner on February 23, 1999, which is incorporated by reference. U.S. Patent No. 5,874,914 20 discloses a GPS receiver in one embodiment which includes an antenna which receives GPS signals at an RF frequency from in view satellites; a downconverter coupled to the antenna for reducing the RF frequency of the received GPS signals to an intermediate frequency (IF); a digitizer coupled to the downconverter and sampling the IF GPS signals at a predetermined rate to produce sampled IF GPS signals; a memory coupled to the digitizer storing the 25 sampled IF GPS signals (a snapshot of GPS signals); and a digital signal processor (DPS)

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coupled to the memory and operating under stored instructions thereby performing Fast Fourier Transform (FFT) operations on the sampled IF GPS signals to provide pseudorange information. These operations typically also include preprocessing and post processing of the GPS signals. After a snapshot of data is taken, the receiver front end is powered down.

- 5 The GPS receiver in one embodiment also includes other power management features and includes, in another embodiment, the capability to correct for errors in its local oscillator which is used to sample the GPS signals. The calculation speed of pseudoranges, and sensitivity of operation, is enhanced by the transmission of the Doppler frequency shifts of in view satellites to the receiver from an external source, such as a basestation in one
- 10 embodiment of the invention.

- Additionally, another example implementation of the time measurement utilizing the assistance of a base station may be implemented in the system described in U.S. Patent No. 5,841,396, entitled "GPS Receiver Utilizing A Communication Link," issued to Norman F. Krasner on November 24, 1998, which is incorporated by reference. U.S. Patent No. 15 5,841,396 discloses a precision carrier frequency signal for calibrating a local oscillator of a GPS receiver which is used to acquire GPS signals. The precision carrier frequency signal is used to calibrate the local oscillator such that the output of the local oscillator, which is used to acquire GPS signals, is modified by a reference signal generated from the precision carrier frequency signal. The GPS receiver locks to this precision carrier frequency signal and 20 generates the reference signal. In another aspect of the invention, satellite almanac data is transmitted to a remote GPS receiver unit from a base station via a communication link. The remote GPS receiver unit uses this satellite almanac data to determine approximate Doppler data for satellites in view of the remote GPS receiver unit.

- Still another example implementation of the time measurement utilizing the assistance of a base station may be implemented in the system described in U.S. Patent No. 25

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5,999,124, entitled "Satellite Positioning System Augmentation With Wireless Communication Signals," issued to Leonid Sheynblant on December 7, 1999, which is incorporated by reference. U.S. Patent No. 5,999,124 discloses a method and apparatus for processing position information from satellite positioning system satellites and from cellular
5 based communication signals. In one example of a method according to the invention, a SPS receiver receives SPS signals from at least one SPS satellite. This SPS receiver is coupled to and typically integrated with a communication system which receives and transmits messages in a cell based communication system. In this method, a message is transmitted in the cell based communication signals between a communication system and a first cell based
10 transceiver. A time measurement which represents a time of travel of a message in the cell based communication signals between the cell based transceiver and the communication system is determined. Another time measurement that represents a time of travel of the SPS signals is also determined. A position of the SPS receiver is determined from a combination of at least the time measurement which represents the time of travel of a message in the cell
15 based communication signals and from a time measurement which represents a time travel of the SPS signals. The cell based communication signals are capable of communicating data messages in a two-way direction in one embodiment between the cell based transceiver and the communication system.

Another example implementation of the time measurement utilizing the assistance of
20 a base station may be implemented in the system described in U.S. Patent No. 6,002,363, entitled "Combined GPS Positioning System And Communications System Utilizing Shared Circuitry," issued to Norman F. Krasner and is incorporated by reference. U.S. Patent No. 6,002,363 discloses a combined GPS and communication system having shared circuitry. The combined system includes an antenna for receiving data representative of GPS signals, a
25 frequency converter coupled to the antenna, a frequency synthesizer coupled to the

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frequency converter, an analog to digital converter coupled to the frequency converter and a processor coupled to the frequency converter. The processor processes the data representative of GPS signals to determine a pseudorange based on the data representative of GPS signals to determine a pseudorange based on the data representative of GPS signals.

- 5 The integrated communication receiver includes a shared component which is at least one of the antenna, the frequency converter, the frequency synthesizer and the analog to digital converter. Typically, in certain embodiments, the processor also demodulates communication signals received as well as controls the modulation of data to be transmitted as a communication signal through a communication link.

- 10 While various embodiments of the application have been described, it will be apparent to those of ordinary skill in the art that many more embodiments and implementations are possible that are within the scope of this invention. Accordingly, the invention is not to be restricted except in light of the attached claims and their equivalents.